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Understanding Complexity and Self-Organization in a Defense Program Management Organization (Experimental Design)

18 March 2016

Raymond Jones, Lecturer

Graduate School of Business & Public Policy

Naval Postgraduate School

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Introduction

The Department of Defense (DoD) spends at least 60% of its budget for the acquisition and sustainment of new material capability and services. The DoD's track record with regard to maximizing value from this investment has been poor, to say the least, and warrants a more in-depth understanding of the root cause of the problem. The lack of a successful integrated network approach to the problem of poor program performance is evident in the many significant cost and schedule program overruns and the failure of legislation and policy emanating from initiatives such as the Packard Commission study, Goldwater-Nichols Legislation, and more recently, the Better Buying Power initiative.

While the DoD acquisition framework is well defined and incorporates a variety of disciplines such as systems engineering, budgeting, contracting, test and evaluation, and so forth, it does not address the fundamental variable that those responsible for administering the process do not necessarily behave in linear and predictable ways. The current acquisition decision support system of requirements development, budgeting, and acquisition management (Figure 1) presumes that "fact of life" variation throughout the life of the program can be managed in a predictable way and that the acquisition workforce behaves under the *Homo economicus*, or economic man, principle. The economic man is the concept in many economic theories which portrays humans as consistently rational and narrowly self-interested agents who usually pursue their subjectively-defined ends optimally.

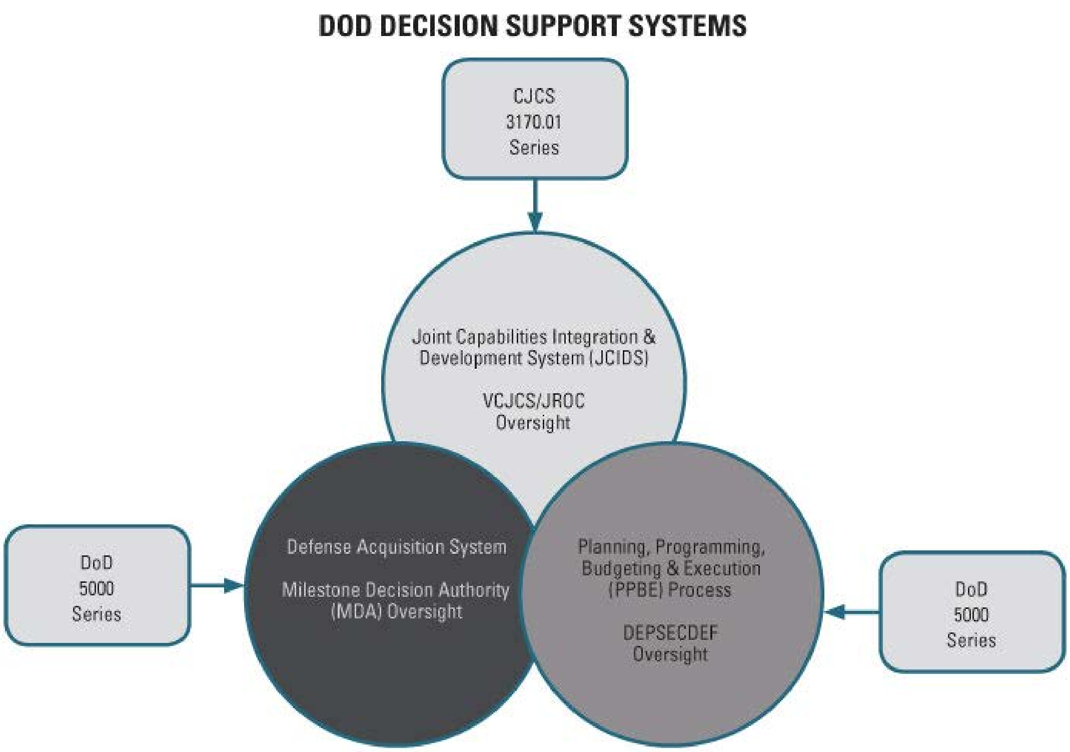

Figure 1. Defense Acquisition Decision Support System (DSS) (DAG, 2011)

The acquisition process within the DSS and described in DoD 5000.02, consists of a multi-phase process designed to integrate systems engineering, budgeting, and management across the program through time (Figure 2). Within each of the phases are key decision and knowledge points at which decision-makers assess the overall performance of the program relative to the key program attributes of cost, schedule, and performance.

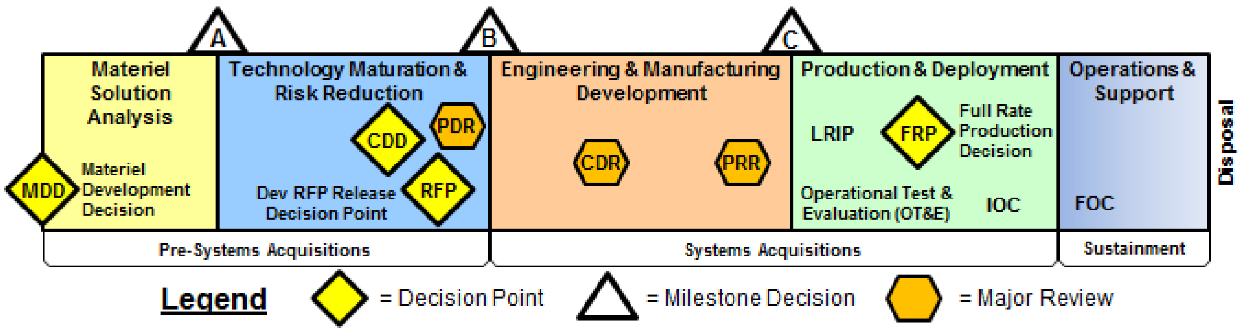

Figure 2. Defense Acquisition Process (DoD 5000.02, 2015)

Reforms to the defense acquisition process have focused on the methodological procedures of the acquisition process providing only partial remedies because they do not address incentives to deviate from defined practices. Weapons acquisition is a complicated enterprise, complete with unintended incentives that are motivated by the perceived and real circumstances within which the program is performing. These incentives stem from several factors. For example, the different participants in the acquisition process impose conflicting demands on weapon programs so that their purpose transcends just filling voids in military capability. The budget process forces funding decisions to be made well in advance of program decisions, which encourages undue optimism about program risks and costs. Finally, program office personnel respond to the changing environment based upon their intrinsic understanding of the business conditions and their level of experience and comfort in this complex procurement environment.

Concept and Scope

This proposed research experiment will examine the decision-making process within the program office and the self-organization of key program office personnel based upon formal and informal communications links. Additionally, we are interested in the effects of this self-organizing process on the organization's shared situational awareness and ultimately how these decisions evolve and impact overall program performance.

This experiment will help us determine the impact of individual relationships within a program office and how their decision-making and task execution impacts the overall performance of a program. We will examine these relationships by observing the communications network within the organization and the various

formal and informal ties that manifest themselves as a program progresses through the acquisition process.

The focus of this experiment will be an Acquisition Category 1D (ACAT1D) program. We will use the Airborne Joint Tactical Radio System (AMF) program as our program of reference due to the extensive data available for this program. The descriptive model, which is a process that describes real-world events and the relationships between factors responsible for them, for the self-organizing communications process relationship is shown in Figure 3. There are 10 attributes in this descriptive model, which are considered intervening variables. An *intervening variable* is an internal state that is used to explain relationships between observed variables, such as independent and dependent variables. With the exception of the formal and informal communications pathways, we will hold all of the attributes constant throughout the experiment.

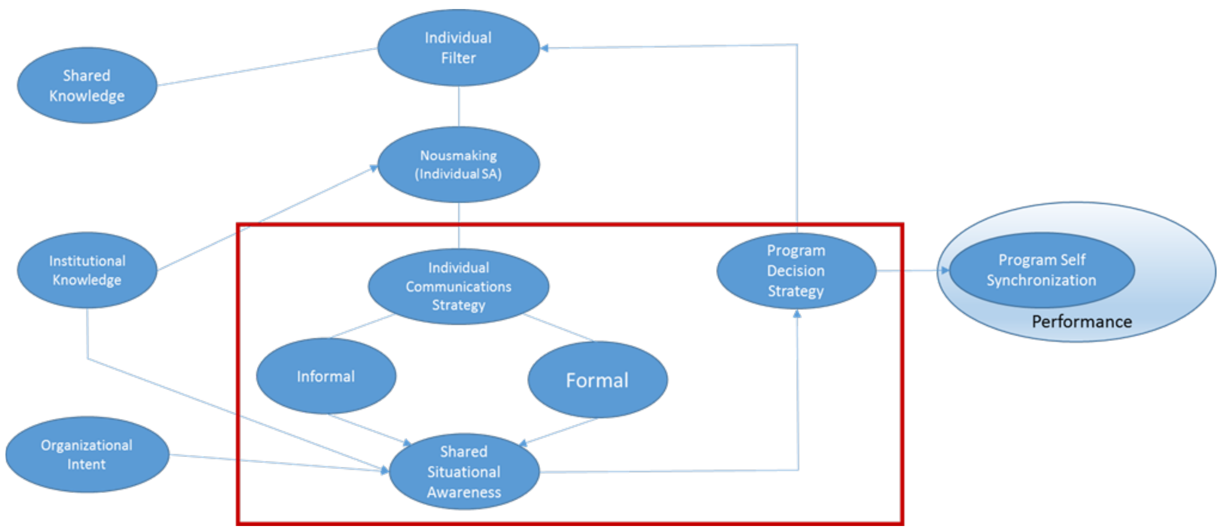

Figure 3. Self-Organizing Descriptive Model for a Defense Acquisition Program Office

Nousmaking

I refer to the process of individual situational awareness (SA) as Nousmaking, which is the degree to which the decision maker optimizes four aggregate categories; explicit knowledge, tacit knowledge, trust, and sensemaking and is able to make high quality decisions in ambiguous environments. Nousmaking comes from the term Nous, which means to have intelligence and have the ability to make good judgments and decisions (Webster, 2016). In essence, the individual is determining what is real through the interaction of the four aggregate categories. These aggregate categories were derived from previous research conducted on Special Operations soldiers' decision-making process in complex and volatile conditions. The results of this research are documented in *The Creation of Nous through the Interaction of Sensemaking, Trust, Tacit Knowledge and Explicit Knowledge and its Relationship to Decision Making in Complex and Chaotic Environments* (Jones, 2015). The degree to which the individual optimizes the

aggregate categories and is able to make timely and high quality decision determines the overall effectiveness of the decision. While this is a significant attribute in the descriptive model with regard to understanding the human impact on the acquisition process, we will simply measure the observable communication patterns, as a result of the independent variable changes during this experiment and leave the relationship of Nousmaking on the overall performance to future research. The relationship to the network communications structure and the descriptive model is shown in figure 4.

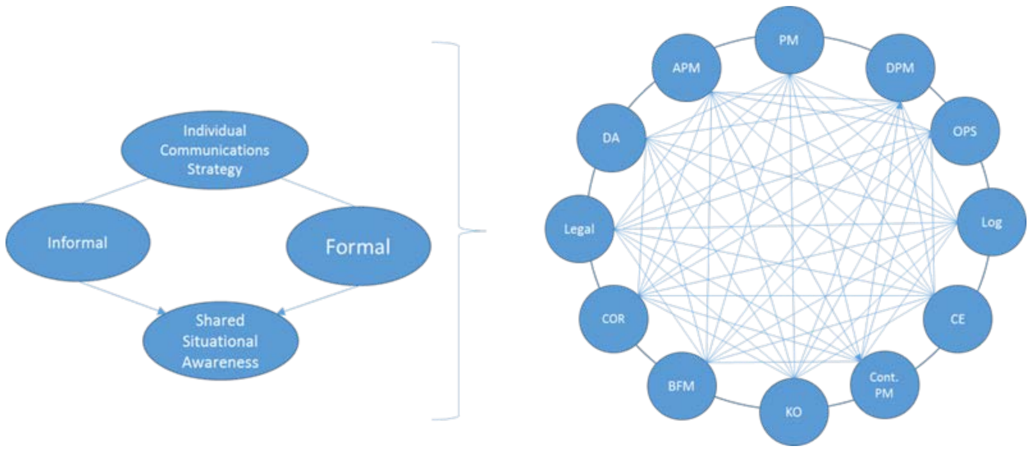

Figure 4. Self-Organizing Network Communications Pattern

(Note: Network structure on the right depicts all the potential communications pathways in an organizational structure)

Self-Organizing Network Behavior

The nodes in the network are specific individuals within well-defined organizational positions. Individuals must meet certain pre-requisites to be qualified for their respective position. These pre-requisites are based on the Defense Acquisition Workforce Improvement Act (DAWIA) legislation, which mandated a certain certification level for critical acquisition positions. For the purposes of this experiment, we will use actual program office personnel with the appropriate DAWIA certification levels. The strength and manner in which communications manifest themselves within the program office results in the self-organizing effect, which ultimately impacts the program decision strategy (de Montjoye, Stopczynski, Shmueli, Pentland, & Lehmann, 2014).

There are fundamentally three communications links we will examine for this experiment: expressive, instrumental, and structural (Table 1). These networking relationships are based upon research by de Montjoye et al., in which performance was strongly correlated with the network of expressive and instrumental ties. These three communications relationships form the basis of the dynamic network of shared understanding within the program.

Table 1. Communications Network Ties

Ties	Definition
Instrumental	Ties which arise in professional settings, between colleagues interacting and spending time together.
Expressive	Ties that reflect friendship or personal relationship and include an affective factor.
Structural	Ties which are predictable based upon the pre-defined organizational communications structure.

Data will be collected to measure the strength of the ties within the formal and informal communications network as the program proceeds through a time-phased scenario that simulates the technology development phase of the program. Figure 5 shows the formal organizational command and control structure and linear communications pathways relative to all possible communications network ties within a program office.

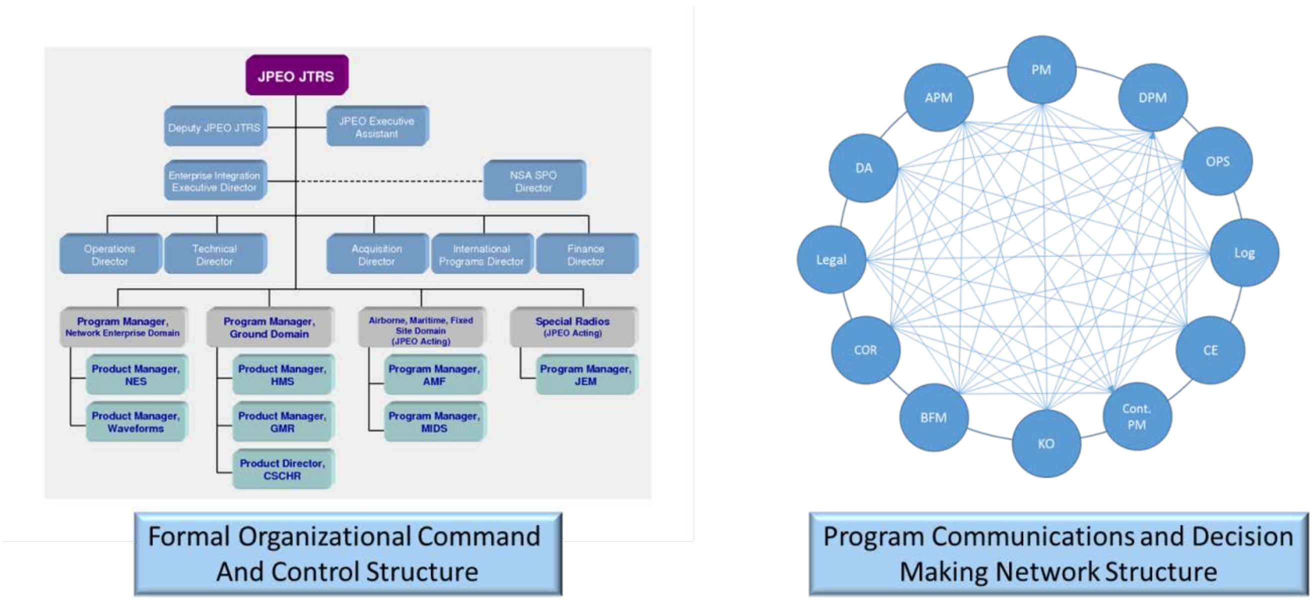

Figure 5. Organizational Structure Relative with Self-Organizing Network Structure

The program communications and decision-making network structure reflects the links that develop as a result of the self-organizing process within the program office and ultimately informs the program decision strategy.

Participants for this experiment will include Level III certified government acquisition professionals and industry representatives. Eventually, this research will involve the following five phases of the experimental process:

- Phase 1: Definition and experimental design

- Phase 2: Discovery experiment execution involving Level III certified acquisition professionals representing critical program office acquisition positions
- Phase 3: Preliminary hypothesis testing to examine decision and behavior pattern impacts of changing predetermined independent variables
- Phase 4: Refined hypothesis testing to examine how decision and behavior variation will support organizational and process changes to improve program value and return on investment
- Phase 5: Conduct demonstration to validate findings and potential for future modeling to support improved acquisition decision-making

This paper addresses the first two in that the initial experiment will be a discovery type experiment, which will lead to the formulation of an initial hypothesis for follow-on experimentation. This experiment will be aligned around the following question: How do the communications and information exchange patterns within a program office impact the overall program performance outcomes. More specifically, given that there are formally established communications requirements (ties) within a program office, how do these communications ties vary and influence the decisions within an ACAT ID program office chartered to develop a highly complex networking radio system?

Literature Review

This literature review will provide a summary of relevant research within the field of decision-making and network theory to help us better understand the relevant nature of the individual impact on organizational outcomes. We will look at how string ties between individuals impact the collaborative problem solving process, systems thinking and complexity, and self-organizing behavior in an organization.

Strong Ties in Collaborative Problem Solving

There is a growing body of evidence to suggest that an organization's performance is related to the strength of the ties between individuals and teams through the formal and informal information networks within an organization. De Montjoye et al. (2014) suggested that a team's performance is strongly correlated with its networks of expressive and instrumental ties and that only the strong ties will have an appreciable impact on the overall performance. They conducted a qualitative and quantitative study on the performance of 45 teams looking at the performance outcomes of these teams relative to their information network ties. Previous understanding of these relationships has been difficult to quantify in that the understanding of the relationship between social connectivity, information flow, and team performance has existed in the form of advice, expertise, and implicit and tacit knowledge. The research of de Montjoye et al. (2014) built upon the advances in social network analysis, showing the impact of an individual's information or collaboration network on their performance. Essentially, they concluded that the

structure of social interactions can enhance or hinder access to relevant information, thus impacting overall performance. Additionally, they bridged the literature on team performance and information networks, leading them to the conclusions that only the strong ties within these networks explained more of the performance variance than any other factor within the teams.

Their work is significant and directly relates to the proposed experiment in that we are exploring the impact of internal communications networks within a defense program organization and the effects of these network ties on the overall performance of the program. Understanding that there are varying levels of communications networks within a program office and that these networks could have an impact on program performance will help us to establish potential cause and effect based upon the strength and centrality of these network connections relative to the formal structural patterns of expected communications.

Systems Thinking and Complexity

Systems engineering provides proven methodologies to analyze and define the management function. In fact, as an analytical process, systems engineering decomposes system problems into component parts to provide for an optimal solution. In the case of program business functions, these analytical steps include a quantitative evaluation of the relationships and interactions among and between the key variables in the program office, manpower, information systems, and stakeholders and their interdependencies.

The systems engineering principle of decomposition provides a methodological process to not only identify, but also measure the inputs, the time and cost associated with the process itself, and the outputs. For the same reason systems engineering uses requirements traceability to ensure adherence to system requirements, the analytical process provides a means of comparing business process outputs to the inputs, as well as measuring those outputs in terms of efficiencies and effectiveness.

Systems engineering supports the development and maintenance of good design. That design leads to decisions in weapon systems development. In this analysis of program office business processes and network communications structures, we should be able to identify either an improved design for the flow of information or a self-organizing social network that reflects the positive or negative effects of the program environment. The result of this analysis could be an improved design for the flow of information within the management function of the Program Management Organization (PMO). The emphasis of the management work needs to be on the management system, rather than the piece parts and daily responses typical of the PMO workday.

Systems thinking and its application to management have received great attention. Early studies emphasized the importance of defining management as a systems activity (Jenkins & Youle, 1968; Johnson, Kast, & Rosenzweig, 1964;

Sterman, 1996). More recently, the continued development of systems engineering as discipline has fostered a renewed interest in applying systems thinking and systems engineering principles to management problems (Checkland, 1994; Sage & Rouse, 2009). A systems approach to project management would complement the increased emphasis of systems engineering and weapon systems development. Key to this idea is that system engineering management of the technical aspects of development should be mirrored by a systems approach in the management of that technical effort (Feigenbaum & Sasieni, 1968).

A constant theme in the management science literature is the criticality of addressing project complexity. It is important to recognize that managerial and technical complexity, coupled with the limits of human capability, has resulted in managerial and technical specialization. The specialists are experts in their particular field, but that local, limited knowledge of the field precludes identifying potentially optimal solutions to interdependent program problems (Amaral & Uzzi, 2007). Specialization has a limiting function, in that the specialists in a PMO are measured by, and capable of, addressing only those issues in their specific area. This suggests that requests for information or expertise outside a specialist's area may have a debilitating effect on the efficiency and effectiveness of the PMO.

Self-Organizing Systems

While defense program organizations have evolved into functionally aligned processes with certified experts in each of these discrete functional domains, it is precisely this phenomenon that creates the potential for an organization to seek a functional decision-making equilibrium beyond the prescribed formal organizational structure. Waldrop (1992) suggests that balancing between rigidity and turbulence is necessary for adaptation and self-organization. This is commonly referred to as "the edge of chaos." According to Heylighen (2008), complex systems are modeled as agents and act upon their environment in response to the events they experience. Additionally, these agents are assumed to be goal-directed and their actions tend to maximize their individual "fitness" or preferences.

Defense program management organizations are structured to meet the cost, schedule, and performance objectives of their respective technology requirements. The processes they follow are well defined in both statute and regulations, and all individuals are "trained" in their respective functional areas and generally have some level of experience in these domains. These organizations are generally rigid in nature with very little variation from doctrinal design. This experiment will examine the extent to which a defense program office self-organizes as a program becomes more turbulent and how the complex network of social interaction and decision-making changes from its perceived base state as defined by regulation and law. *Self-organization* is defined as the spontaneous emergence of global structure out of local interactions (Heylighen, 2008). The spontaneous nature of an organization suggests that there is no internal or external control over the process; rather, it is being shaped by individuals reacting to the environment and potentially changing the inherent network structure within an organization.

Ashby (1962) refers to this phenomenon as a system changing itself from a "bad" way of behaving to a "good" way of behaving. Essentially, as a program organization becomes less productive, it will self-organize in an effort to become more productive. Given the opportunity to self-organize to an optimal state, unfettered by organizational inertia, the organization should seek equilibrium between its original rigid state and a chaotic state, thus achieving a higher degree of performance.

The work of Levitt, Thomsen, Christiansen, Kunz, Jin, and Nass (1999) explore, extend and operationalize Galbraith's (1973) information processing view of organizations. Levitt et al. studied project work processes, organizational micro-contingency theory, and organizational design using Virtual Design Teams (VDTs). These VDTs simulated the micro-level information processing, communications, and coordination behavior of participants, predicting participant and project-level performance. Additionally, follow-on simulations included measures of activity flexibility, complexity, uncertainty, and interdependence strength between nodal relationships. Their simulations sought to model more flexible organizations executing less routine processes, bridging the gap between cognitive and social psychological micro-organization theory and sociological and economic macro-organizational theory for project teams. This work will provide a reference by which the dynamic nature of a PMO changes based upon environmental inputs, and the interrelationship with the social bureaucratic influences.

Experimental Research Design

The Joint Tactical Radio System (JTRS) is a family of affordable, high-capacity, programmable, multi-band/multi-mode tactical radios designed to provide both line-of-sight and beyond-line-of-sight communications capabilities to warfighters. JTRS uses software-defined radio technology to achieve the needed flexibility, upgradeability, and interoperability. JTRS is an enabler for conducting joint operations with full spectrum dominance. The goal of the JTRS program is to develop a radio system that satisfies the requirements stated in the Capabilities Development Document (CDD) approved by the Joint Requirements Oversight Council (JROC). This document calls for the radio system to be "software-reprogrammable, multi-band/multi-mode capable, networkable, and provide simultaneous voice, data and video communications with low probability of intercept. These requirements will ensure that the radio system will be able to interoperate with legacy radios using their existing waveforms, a concept known as backward compatibility. Figure 6 shows the operational view for the JTRS program.

JTRS is organized into five ACAT 1D program offices, each with the requirement to develop a networking system for different parts of the overall network air, ground, and sea battlespace. We will focus on one of these ACAT ID programs—the Airborne, Maritime, Fixed Station Program.

Parameter Space Identification

To better understand the influence of the communications network on the program decision-making strategy, we must identify the parameters within which we will assess our fundamental question and later develop a refined hypothesis. The three primary groups we are interested in defining are the dependent, independent, and intervening variables. These can be described as design variables, criteria space, and functional constraints, respectively, within the parameter space identification (PSI) framework. Table 2 shows the variables for this experiment within the context of the PSI framework.

Table 2. Experimental Variable Within the PSI Framework

Design Variables (Independent Variables)	**Description**
Budget Variance	Program budget will be changed at specific points in the timeline to assess the impact on the criteria space.
Time Variance	Program time constraints will be changed at specific points in the timeline to assess the impact on the criteria space.
External Program Threats	External threats are the levels of program advocacy by program sponsors and stakeholders over time. The range of program advocacy variation that will be scored on a scale of 1-10.
Functional Constraints (Intervening Variables)	
Instrumental Communications Link	These are ties which usually arise in professional settings, between colleagues interacting and spending time together. (Instrumental ties will be reflected by the color green to show the central tendency of instrumental ties within the organization during key decision periods.)
Expressive Communications Link	These are ties that reflect friendship or personal relationship and include an affective factor. (Expressive ties will be reflected by the color red to show the central tendency of instrumental ties within the organization during key decision periods.)
Structural Communications Link	These ties are predictable based upon the pre-defined organizational command and control structure. (Structural ties will be reflected by the color black to show the central tendency of structural ties within the organization during periods of key decision-making.)
Criteria Space (Dependent Variable)	
Program Cost	Program cost will be measured by the amount of variation from the program performance measurement baseline at the start of the program.
Program Schedule	Program schedule will be measured by the amount of variation from the program performance measurement baseline at the start of the program. Earned value management data will be used to determine program schedule variance.
Program Performance	Program performance will be measured by the amount of variation from the program Key Performance Parameters (KPPs) as a function of time. The measures of effectiveness (MOEs) will be based upon predetermined technology readiness levels, defined in Table 3.

Technology readiness levels (TRLs), as defined in the 2011 DoD Technology Readiness Assessment Guidance, are a method of estimating technology maturity of critical technology elements (CTEs) of a program during the acquisition process.

They are determined during a Technology Readiness Assessment (TRA) that examines program concepts, technology requirements, and demonstrated technology capabilities. TRLs are based on a scale from 1 to 9, with 9 being the most mature technology. The use of TRLs enables consistent, uniform discussions of technical maturity across different types of technology.

Table 3. Technology Readiness Level (TRL) Definitions

	Description
TRL 1.	Basic principles observed and reported
TRL 2.	Technology concept and/or application formulated
TRL 3.	Analytical & experimental critical function and/or characteristic proof-of-concept
TRL 4.	Component and/or breadboard validation in laboratory environment
TRL 5.	Component and/or breadboard validation in relevant environment
TRL 6.	System/subsystem model or prototype demonstration in a relevant environment (ground or space)
TRL 7.	System prototype demonstration in a space environment
TRL 8.	Actual system completed and “Flight qualified” through test and demonstration (ground or space)
TRL 9.	Actual system “Flight proven” through successful mission operations

The relationship between the variables is shown in Figure 7. As the independent (design) variables are changed in accordance with (IAW) a pre-determined interval, we are interested in observing the change in the dependent (criteria space) variables and correlating this change with the strength of the ties within the communications network (intervening variables).

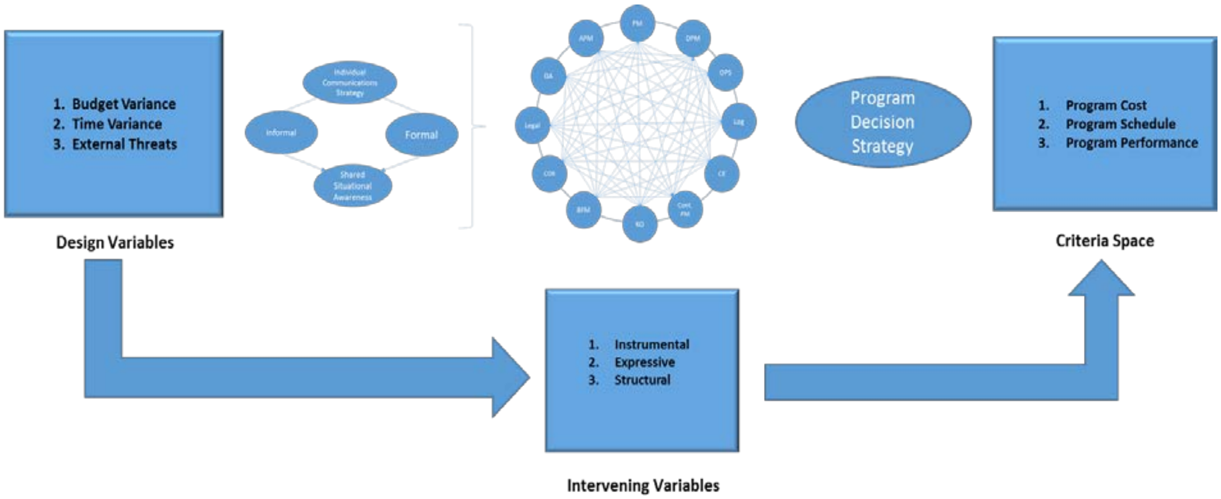

Figure 7. Parameter Space Variable Relationship

The independent variables—budget, time, and external threats—will be varied throughout the experiment at key points, and the dependent variables of cost, schedule, and performance will be measured in relation to the variation in the design variables. Additionally, we will observe the variation and link strength between nodes in the intervening variables and compare them to the criteria space as well as analyze them via a Pareto analysis method to determine which intervening variables have the most significant impact on the criteria space. Pareto analysis is a technique used for decision-making based on the Pareto principle and known as the 80/20 rule. It is a technique that statistically separates a limited number of input factors as having the greatest impact on an outcome, either desirable or undesirable. Pareto analysis is based on the idea that 80% of a project's benefit can be achieved by doing 20% of the work, or conversely, that 80% of problems are traced to 20% of the causes.

Pareto Set Relationship

While this experiment is concerned with the impact of the independent variable in the criteria space, we are also focused on the relationship of the intervening variables with the criteria space and how these network ties tend to influence the variation in cost, schedule, or performance of the program. There are 10 attributes in the descriptive model for this experiment. Initially, we will only allow the informal and formal communications pathways to vary, and we will measure this variation with regard to the strength of their links in the form of expressive, instrumental, and structural strengths and weaknesses, as defined in Table 1.

Using the Pareto analysis methodology, this will reveal which of these links has the greatest impact on the dependent variables. Figure 8 reflects how 20% of the intervening variables might result in at least 80% impact on the criteria space.

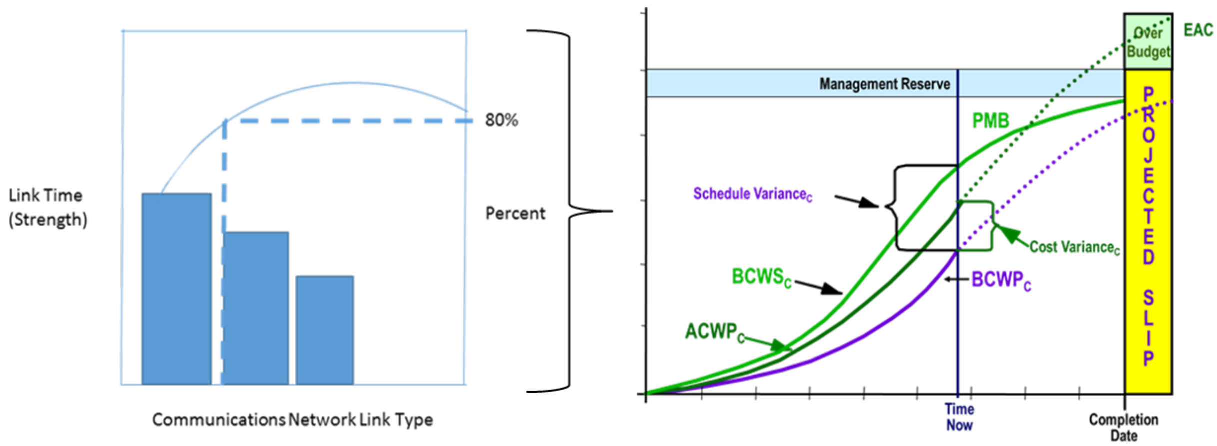

Figure 8. Pareto Chart Showing the Relationship of Intervening Variables

The variance of the criteria space is presented in terms of an earned value calculation, which allows us to determine the level of expected performance value achieved based upon the cost and schedule of the program. Table 4 provides a definition of key earned value terms.

Table 4. Earned Value Management Key Terms

Acronym	Term	Meaning
BCWS	Budgeted Cost for Work Scheduled	Plan - Baseline - PMB
BCWP	Budgeted Cost for Work Performed	Earned Value
ACWP	Actual Cost of Work Performed	Actuals
BAC	Budget At Completion	Planned Cost
EAC	Estimate At Completion	Forecasted Cost
SV	Schedule Variance	Accomplishment Variance
CV	Cost Variance	Earned Value vs Actual Cost
VAC	Variance At Completion	Forecasted Overrun / Underrun

Subsequent experiments will examine additional intervening variables identified in the descriptive model. While these variables will likely have an impact on the criteria space, the most complex set of intervening variables lies within the

formal and informal communications networks. By limiting our initial experimental approach to just the communications network variables that lead to the program decision strategy, we are reducing the overall complexity of the experiment and improving the overall validity of the results.

Conclusions

This experimental design paper describes the discovery experiment phase of an overall experimental process that is intended to provide greater insight into the root cause of defense program execution challenges. This experiment will set the conditions for follow-on hypothesis testing that will examine the effects of internal communications networking relationships and their impact on the value of a program as defined by cost, schedule, and performance.

If characteristic patterns emerge and can be measured and predicted based upon the variation of a program from its initial conditions, then the potential exists for identifying policy, organizational, and training changes from existing methods that could have favorable impacts on program outcomes.

Developing an experiment to examine participant performance and decision-making patterns and impacts in a controlled program scenario could provide data for the continuous refinement of predictive analytical decision patterns within a complex program. Additionally, the experimental process can provide a robust training environment for future program teams to prepare from the complex and ambiguous program environments prior to actually taking over a major defense acquisition program.

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